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Different Brain Activities Predict Retrieval Success during Emotional and Semantic Encoding

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Abstract

■ There is an increasing line of evidence supporting the idea that the formation of lasting memories involves neural activity preceding stimulus presentation. Following this line, we presented words in an incidental learning setting and manipulated the prestimulus state by asking the participants to perform either an emotional (neutral or emotional) or a semantic (animate or inanimate) decision task. Later, we tested the retrieval of each previously presented word with a recognition memory test. For both conditions, the subsequent memory effect (SME) was defined as ERP difference between subsequently remembered and forgotten words. Comparing the prestimulus SME between and within the two conditions yielded topographic differences in the time interval from −1300 to −700 msec before stimulus onset. This indicates that the activity of brain areas involved in incidental encoding of semantic information varied in the spatial distribution of ERPs, depending on the emotional and semantic requirements of the task. These findings provide evidence that there is a difference in semantic and emotional preparatory processes, which modulates successful encoding into episodic memory. This difference suggests that there are multiple task-specific functional neural systems that support memory formation. These systems differ in location and/or relative contribution of some of the brain structures that generate the measured scalp electric fields. Consequently, the cognitive processes that enable memory formation depend on the differential semantic nature of the study task and reflect differences in the preparatory processing of the multiple semantic components of a word's meaning. ■

INTRODUCTION

Learning is probably one of the most important mental functions in humans and animals. The process of acquiring skills, understanding, and knowledge relies on the capacity of the brain to encode new experiences into long-term memory.

Otten, Quayle, Akram, Ditewig, and Rugg (2006) showed that the formation of a lasting memory depends not only on the neural activity evoked by the event itself but also on the activity that precedes stimulus presentation. This activity represents anticipatory processes that play an important role for learning efficiency (Otten, Quayle, & Puvaneswaran, 2010). However, this result was only found in connection with different semantic encoding tasks (when subjects were asked to judge the animacy of presented nouns or the relative size of words' referents), but not in connection with a nonsemantic orthographic encoding task. What still remains unclear is whether prestimulus emotional processing affects the memorability of our experiences.

It has been shown that emotional information strongly influences language comprehension on word level (Hare, Jones, Thomson, Kelly, & McRae, 2009). Thus, semantic processing also involves the emotional valence of stimuli when we access the words' meaning (Carretie et al., 2008; Kissler, Assadollahi, & Herbert, 2006). For this reason, we wondered if there might be differences between a nonemotional semantic decision task and a task requiring a judgment about the emotional valence of words in the time before the stimulus presentation and also whether these processing modes affect successful encoding.

Considerable insights in our understanding of the neural correlates underlying memory encoding are owed to an experimental paradigm known as the subsequent memory paradigm (Paller & Wagner, 2002; Friedman & Johnson, 2000; Paller, Kutas, & Mayes, 1987; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). This paradigm correlates neural activity during encoding with later remembering. The comparison of the brain activity patterns corresponding to remembered and forgotten items yields a key contrast: the subsequent memory effect (SME). Such an approach to the study of memory formation potentially allows predictions as to whether an event will be later remembered or forgotten.

The subsequent memory paradigm has been widely used to study memory encoding (Otten, Henson, & Rugg, 2002; Paller & Wagner, 2002; Friedman & Johnson, 2000; Paller et al., 1987; Sanquist et al., 1980). In one of these studies, Otten and colleagues (2002) showed that a sustained

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activation could exert a slow modulation on the encoding process across short task blocks of stimuli. From this finding, it was reasonable to assume that the sustained activation was not the only factor to influence the neural activity in the time preceding a single stimulus presentation but that the prestimulus activity could also affect successful encoding. This prediction was confirmed on a trial-by-trial basis by Otten et al. (2006). In their study, an incidental encoding task was associated with either a semantic decision (animate or inanimate entity) or an orthographic decision task (whether the first and last letters of the word were or were not in alphabetical order). The participants were told by a cue which of the two decision tasks they were going to perform on an upcoming word. Remarkably, when participants performed the semantic decision task, the waveforms preceding the presentation of the words were different for remembered and forgotten words; whereas these differences were absent in the case of the orthographic decision task for upcoming stimuli (Otten et al., 2006). In a recent article by the same authors, these prestimulus effects were replicated in the visual modality and extended to auditorily presented words. A functional interpretation of these results suggests that "prestimulus activity might reflect the degree to which semantic processes can be prepared ahead of an event" (Otten et al., 2010). This conclusion was based on the consideration that in both experiments the prestimulus effects on memory encoding appeared to be related to a task in which the meaning of the word had to be accessed. The adoption of a proper semantic task set might influence the formation of a deeper and more elaborated representation easier to retrieve during recall (Otten et al., 2010). In addition, the notion of an encoding-related semantic task set and the prefrontal ERP negativity associated with these prestimulus effects seem to coincide with the slow frontal negativity pattern observed in working memory control processes. This pattern also involves the activation of posterior cortical systems that participate in the initial perception and comprehension of the retained information (Ruchkin, Grafman, Cameron, & Berndt, 2003). In this sense, the type of task to be performed can determine, at least in part, the prestimulus effects, which could be explained in terms of the Level of Processing Theory (Craik & Lockhart, 1972), as reported in several studies demonstrating the SMEs (Paller & Wagner, 2002; Friedman & Johnson, 2000; Paller et al., 1987). Taken together, these studies suggest that the SMEs reflect processing differences, which occur when subjects maintain a meaning-based attentional orientation in meaning-based tasks.

The question here is whether prestimulus processing shows a different pattern of neural activity when subjects have to focus on the emotional valence of a word meaning. Investigating the relation between emotional and semantic processing in a series of experiments, Storbeck and Clore (2007) concluded that emotional and semantic features are represented in a common network of brain regions involved in semantic processing. Converging evidence from neurolinguistic (Pulvermuller, 1999) and cognitive semantic (Barsalou, 1999) research states that this semantic network has dynamic properties and can comprise different neural networks, which represent the different aspects of a word's meaning, such as animacy (animate or inanimate judgments) or emotional connotations (neutral or emotional judgments; Kissler et al., 2006; Assadollahi & Rockstroh, 2005). Differential brain activation related to these networks, reflecting functional divisions of the semantic system, has been repeatedly shown for specific object categories, attributes, or types of knowledge (Binder, Desai, Graves, & Conant, 2009). In addition, a recent fMRI study focusing on the neural networks underlying emotional and semantic priming reported a neural dissociation between the two types of priming (Liu, Hu, Peng, Yang, & Li, 2009).

Following these lines of evidence, we will use the terms emotional and semantic processing to refer to the neural activity preceding a stimulus event, induced by decision tasks requiring the use of different connotations (emotional vs. semantic) of a word meaning. This neural activity is thought to reflect a stimulus processing preparation, which emphasizes the role of prestimulus activity in memory encoding.

In this article, we intend to investigate whether this prestimulus activity differs between emotional and semantic elaboration modes and whether these two modes are associated with different types of semantic processing. For this reason, we pursue two aims: first, to inquire how this prestimulus activity modulates the neural mechanisms that lead to memory formation in the emotional mode, independently of the activity elicited by the event itself. Second, to compare the responses related to successful encoding evoked by emotional processing with the responses evoked by nonemotional semantic processing to establish differences between the two modes of processing. To our knowledge, no research has been reported on the SME of emotional processing in the time preceding word presentations. To achieve these goals, we compared the neural processes elicited from two different incidental encoding tasks. In one task, the subjects were asked to judge whether a word belongs to the emotional or to the nonemotional category. In the other task, the subjects were asked to decide whether a word referred to an animate or to an inanimate entity.

We used ERPs combined with the same procedure previously shown to lead to the prestimulus SME in the semantic condition. To define the extent to which the prestimulus SME can be modulated by the type of cue instruction, we focused on the analysis of the neural activity in the time window between a cue (inducing either an emotional or a semantic decision task) and the stimulus (word) onset.

Referring to previous findings, our predictions are based on the following theoretical rationale: Otten et al. (2010) have argued that semantic processing is a prerequisite for observing an SME, as no SME was obtained when the depth of processing did not reach the semantic level. We tried to replicate these effects in the semantic condition. More specifically, we tried to reproduce the increased frontal negativity pattern (electrodes Fp1, Fp2, Fpz, AF1, and AF2) that Otten et al. have repeatedly shown to be an ERP index of the prestimulus SME effect (Otten et al., 2006, 2010).

Furthermore, because in the present study we induce an emotional decision task that depends on accessing the meaning of a word and therefore involves semantic processing, the brain activity before stimulus onset should also differ between subsequently remembered and forgotten words. If the prestimulus SME in the semantic task differs from the prestimulus SME in the emotional task, then this would indicate the existence of multiple and distinct types of semantic processing involved in accessing the emotional and semantic meanings of a word, thereby exerting a different influence on the prestimulus period hence on memory encoding.

METHODS

Participants

A total of 21 university students (mean age = 22.3 years; four men) volunteered to participate in the experiment in exchange for credit or out of personal interest. All participants were native German speakers, in healthy condition and right-handed. All had normal or corrected-to-normal vision. The experimental data were collected after obtaining informed written consent from each subject. The study was in accordance with the regulations of the local ethics committee. All data were recorded at the Institute of Psychology of the University of Bern.

Stimulus Material

A total of 432 concrete nouns were selected from a database of written German words (Baayen, Piepenbrock, & Gulikers, 1995). These words consisted of 4–10 letters and ranged in frequency between 1 and 30 occurrences per million. The nouns were dual-meaning words containing two dimensions of information: an emotional semantic component related to the emotional judgment and a nonemotional semantic component related to the animacy judgment. The words were selected to form four categories of equal size, namely (1) emotional animate (e.g., aggressor), (2) neutral-animate (e.g., tradesman), (3) emotional inanimate (e.g., poetry), and (4) neutral inanimate (e.g., fork). Each word could thus be classified with respect to two independent dimensions: emotional valence (neutral or emotional) and animacy (animate or inanimate). Because there is no complete database for German words, such as the English Self-Assessment Manikin affective rating system for arousal and valence scales (Bradley & Lang, 1994), we presented all the words to each subject in a separate subexperiment and asked them to indicate their own emotional judgments on each item using the same 9-point valence scale and instructions as in English Self-Assessment Manikin affective rating system. Additionally, the rating results on the valence dimension of the emotional words used in the study phase were obtained by merging two different subsets of already validated German words (Lahl, Goritz, Pietrowsky, & Rosenberg, 2009) and a database previously used in other studies (Herbert, Junghofer, & Kissler, 2008; Kissler, Herbert, Peyk, & Junghofer, 2007) with a third part that was validated by our group on 40 German mother tongue students of the University of Bern. In the two categories containing emotional words, half of the items had a positive (M = 6.36, SD = 0.81) and half a negative (M = 2.79, SD = 0.91) valence. The rest of the stimuli had a neutral valence (M = 5.03, SD = 0.82). An additional 16 words were selected from the same database to create a practice list for the study (eight items) and test phase (eight items).

Task and Procedure

The procedure is depicted in Figure 1.

Study: Emotional and Semantic Judgments

During the study phase, volunteers were presented with a random sequence of words, consisting of a subset of 288 nouns (72 from each category, i.e., emotional-animate, neutral animate, emotional inanimate, and neutral inanimate). Every word was preceded by a prestimulus cue, which consisted of the presentation of either the letter O or the letter X. The cue type signaled which decision task had to be performed. After the letter O, the participants had to decide whether the upcoming word was animate (or referred to the property of a living entity). This is defined as the semantic condition. Following the letter X, they had to decide whether the upcoming word was neutral or emotional. This is defined as the emotion condition. Semantic and emotional decisions were equiprobable and randomly intermixed. All stimuli were presented in black letters (font: Courier New 24) on a gray background on a computer screen placed 1.2 m in front of the subject (words length varied between 2.7 and 6.2 cm). Words subtended an approximate vertical visual angle of 0.4° and a horizontal visual angle ranging between 1.3° and 3.1°. The cues were displayed for 2600 msec. They were followed by a 100-msec blank period and the presentation of the word. Each word was presented for 300 msec, followed by a fixation cross for 2200 msec. Thus, each trial had a duration of 5200 msec. After the target presentation, participants had to respond by pressing one of four keys with their left and right middle and index fingers. Both hands were assigned to animate and emotional answers. The middle finger was always used to respond to emotional judgments, and the index finger was used to respond to semantic judgments. This finger assignment was counterbalanced across participants. In the instructions, both speed and accuracy of responses were emphasized.

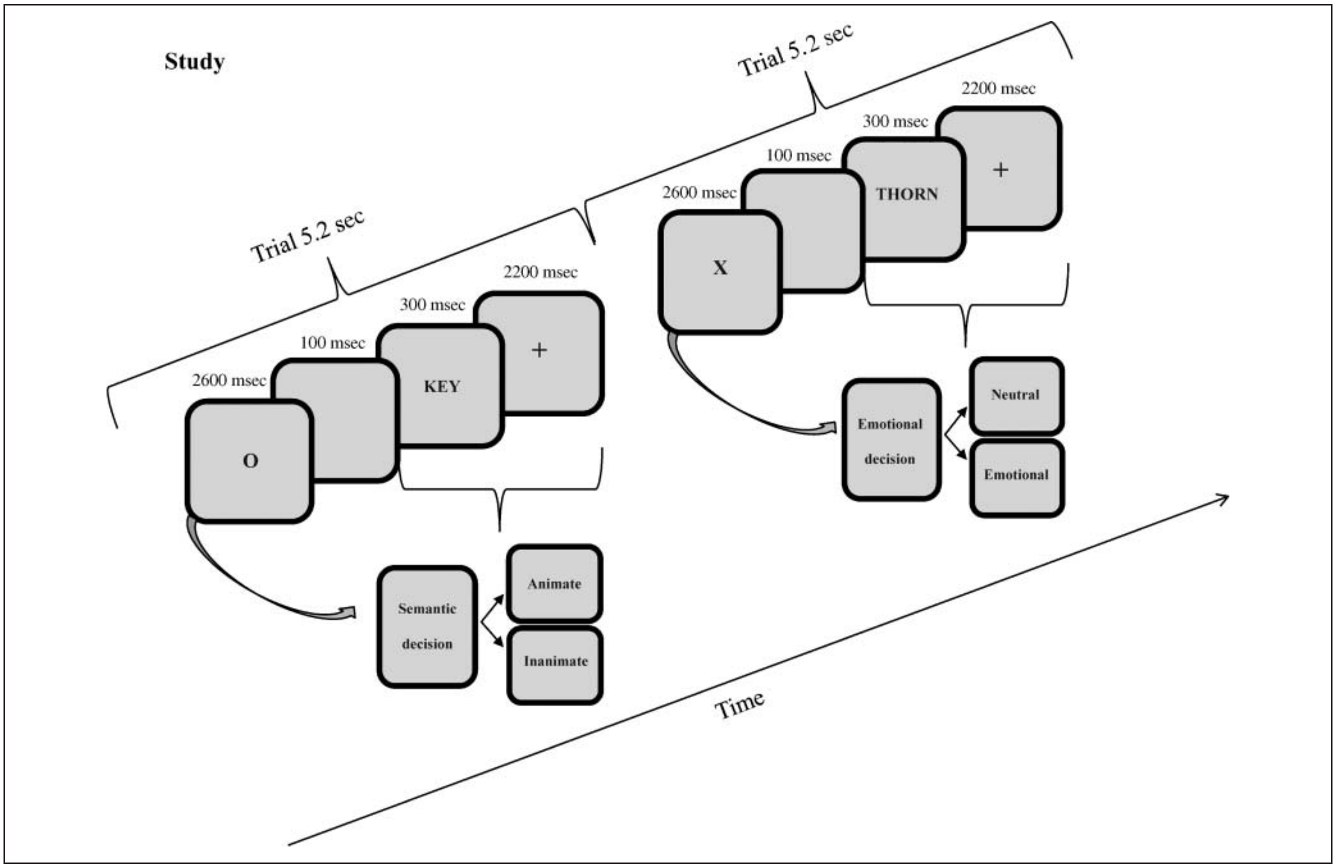


Figure 1. Task designs at study. Encoding phase trial sequence. The cues represented by the letters X or O determined the type of decision task. The appearance of the X cued the subjects to make the emotional decision and O the semantic decision.

Participants undertook a short practice session of the study task, followed by four blocks of 72 trials each. Short pauses were inserted in the middle of each block and between the blocks. The participants were not informed about the surprise recognition memory test.

Test: Recognition Memory

The test for recognition memory followed the study phase after a mean delay of 18 min, during which the volunteers were allowed to rest. For this test, all 288 words presented in the study phase (old words) were used along with 144 new words. The new words were divided into four categories as described above (36 words each). All old and new words were presented once in a random sequence on the computer screen. Before the presentation of each word, an exclamation mark was shown for 1000 msec, serving as a fixation point and as a warning stimulus. The words were visually presented one at a time for 300 msec, followed by a blank screen of 2900 msec. Thus, each trial lasted 4200 msec. Participants were instructed to decide for each word, whether they had seen it in the previous experiment, and to indicate whether they were confident or not about their decision. As before, after the target presentation, participants had to respond by pressing one of four keys with their middle and index fingers. One hand was assigned to respond to the items confidently judged to be old and nonconfidently judged to be old, the other hand to items confidently judged to be new and nonconfidently judged to be new. This hand assignment was counterbalanced across subjects. The index finger was always used to respond to confidently sure judgments, and the middle finger to confidently unsure judgments. No specific instruction was given about how confident someone should be before pressing the confident key. Again, both speed and accuracy were stressed. The test was subdivided into four blocks of 108 items each (72 old + 36 new). As before, short breaks were taken in the middle of each block and between the blocks. For instruction, the practice list of the study phase (with additional new words) was used.

EEG Acquisition and Preprocessing

The EEG was recorded using two 32-channel BrainAmp MR plus amplifiers and an MR 64 channel electro cap with Ag/AgCl electrodes (FMS, Munich, Germany). The volunteers were seated in an electrically shielded and air-conditioned room. The electrode montage included 65 electrodes consisting of all 10–20 system electrodes and the additional electrodes Fpz, FCz, CPz, POz, Oz, Iz, AF1/2, F1/2/5/6, FC1/2/3/4/5/6, FT7/8/9/10, C1/2/5/6, CP1/2/3/4/5/6, TP7/8/9/10, P5/6, PO1/2/9/10, and OI1/2 plus two electrodes below the outer canthus of each eye. The electrodes O1/2 and Fp1/2 were placed 5% more laterally for more even coverage, indicated by an apostrophe in the label (e.g., O1′). The EEG was referenced to the Fz electrode and sampled at 500 Hz/channel with a band pass of 0.01–250 Hz. The impedance was kept below 15 kΩ. The EEG data were preprocessed in Vision Analyzer software (Brain Products GmbH, Munich, Germany), digitally band-pass filtered between 0.01 and 16 Hz, corrected for horizontal and vertical eye movements using an independent component analysis (Jung et al., 2000), and transformed to average reference (Lehmann & Skrandies, 1980). No baseline correction was applied. Residual artifacts were eliminated by visual inspection. Furthermore, in the entire set of data used, a total of 12 channels (1% of all data) had to be interpolated using linear splines (Perrin, Pernier, Bertrand, & Echallier, 1989).

Analysis of Behavioral Data

In both study and test phases, accuracy and RTs were analyzed. Differences in the emotion and semantic conditions were investigated with two-tailed t tests, and the alpha level was set at .05. To assess the recognition accuracy of the test phase, the Pr discrimination index on the basis of the two-high threshold model (Snodgrass & Corwin, 1988) was used ($P_{\text{hit}} - P_{\text{false alarm}}$). The same test was applied to determine the nature of the interaction between confidence (sure or unsure) and type of encoding (emotional or semantic). The basic assumption was that if recognition accuracy was at chance level, the performance measure would not differ from zero.

ERP Analyses

ERP waveforms from each electrode site were averaged across each condition and separately for subsequently remembered or forgotten study words (see Results). Trials with no response or a response faster than 200 msec were excluded, following the literature (Otten et al., 2006, 2010). Furthermore, to ensure an adequate signal-to-noise ratio in the ERPs, participants who had fewer than 12 artifact-free trials per condition were excluded from the analysis. For the main analysis of the data (prestimulus SME), four individual average ERPs were computed for each condition (emotion vs. semantic) and recognition mode (remembered vs. forgotten). The analysis window started at 3000 msec before word presentation (i.e., 300 msec before cue presentation) and ended at the onset of the word. To confirm the validity of the data, we also computed separate post-stimulus average ERPs for subsequently remembered and forgotten words, which allowed us to compare our results with previous studies (Otten & Rugg, 2001; Otten et al., 2006, 2010). These ERP analysis windows started at 100 msec preword and ended at 2 sec after word onset.

The data analysis included two different aspects: In a first part, we attempted to replicate SME findings in the semantic condition as reported in the literature. We expected more negative potentials at prefrontal electrodes for the remembered items before stimulus onset (Otten et al., 2006). We therefore computed moment-by-moment one-tailed t tests, comparing the potentials at electrode Fpz between remembered and forgotten items. In addition, we computed a repeated measure ANOVA for on the average amplitude across five frontal electrode sites (Fp1, Fp2, Fpz, AF1, AF2). These five electrodes were selected according to a priori expectations about a frontal distribution of the SME for words in the semantic condition, as reported in the literature (Otten et al., 2006, 2010).

In the second and main part, we explored the SME in the emotion condition and contrasted it with the semantic condition. Because we had no a priori hypothesis about the latency and scalp distribution of the SME in the emotion condition, we based our main analysis on methods that assess the significance of an ERP effect across the entire scalp, thus protecting the results against false positives.

More precisely, to assess quantitative (amplitude only) differences, we used global field power (GFP) analysis, which is a parametric assessment of map strength, computed as standard deviation of the momentary potential values and independent of topography (Lehmann & Skrandies, 1980). To determine qualitative (topographic) differences, we used topographic ANOVAs (TANOVAs). The TANOVA is an established method for comparing multichannel ERP data, which is based on randomization techniques (e.g., Michel, Koenig, Brandeis, Gianotti, & Wackermann, 2009; Wirth et al., 2007; Strik, Fallgatter, Brandeis, & Pascual-Marqui, 1998). It serves the same purpose as computing an ANOVA with all channels as repeated measures but has the advantage that it considers the entire scalp field, that is, all channels as a single entity and no assumptions about the correlation structure among channels are necessary (Greenblatt & Pflieger, 2004; Lobaugh, West, & McIntosh, 2001; Karniski, Blair, & Snider, 1994, for similar approaches). As with other ERP analysis methods, TANOVAs can be applied to single time instances or to data averaged across intervals. Significant TANOVA effects imply at least partially different sources of the evoked potentials (Strik et al., 1998). Randomization statistics have been shown to have statistical power similar to parametric statistics if the assumptions for parametric statistics hold and to have higher statistical power otherwise (Manly, 2007).

Because possible amplitude differences were already accounted for by the GFP analysis, we chose to use a version of the TANOVA that is based on amplitude-normalized maps, making the results independent of GFP. This allows an unambiguous separation of topographic effects, which must result from a different spatial distribution of the active sources or from a different contribution or weighting of activity at the same source locations. Amplitude differences in the absence of topographic differences indicate that similar source distributions have been active, but with different overall strength.

Before the in-depth analysis, an overall assessment of the significance of differences between experimental conditions was conducted. This analysis was based on time point-by-time point TANOVAs over the entire analysis period, yielding a p value for the main effect of Encoding Condition (two levels: emotion, semantic), Recognition Performance (two levels: remembered, forgotten), and their interaction. The count of significant time-points ($p < .05$) was then compared against the count of p values below .05 expected under the null hypothesis, as derived from the randomized samples (Koenig & Melie-Garcia, 2010). The count of significant time points was larger than chance ($p = .026$) for the interaction, leading to the overall rejection of the null hypothesis of no consistent differences between conditions. Thus, given that on a global level there was evidence for differences, we proceeded with a post hoc analysis to identify in time and space the selected time interval, following the procedure previously used by Otten et al. (2006, 2010). We analyzed consecutive 100-msec intervals to explore the development of the SME over the whole epoch. As before, we computed TANOVAs using the two repeated measures factors: Encoding Condition (two levels: emotion, semantic) and Recognition Performance (two levels: remembered, forgotten) and were specifically interested in interactions of condition and performance for two main reasons: first, because only the interactions integrate these two factors; and second, because neither the main effects nor analyses of a single task condition would be sufficient to justify an analysis period for further in-depth analyses. We found a cluster of adjacent time periods from −1300 to −700 msec where the interactions always yielded a p below 10% interactions, with only one exception in the time −1100 to −1000 msec ($p = .117$).

In a next step, we averaged the ERP potentials in the time range from 1300 to 700 msec before the stimulus onset and computed separate TANOVAs for the SME in the semantic and emotional task condition and a TANOVA with the full 2 × 2 design. Significant effects in this mean interval were further explored using t-maps. The rationale for analyzing data averaged across an extended period was that (a) in the prestimulus interval, one would expect effects to be rather slow and therefore better represented by averages across a period of several hundred msec and (b) all the previous analyses also used ANOVAs on data averaged across averaged time intervals (Otten et al., 2006, 2010).

For comparison with other studies and to complete the first confirmatory ANOVA of the SME in the semantic task condition, we also computed in the time interval from −1300 to −700 an ANOVA for repeated measures on the basis of a selected pool of five electrodes (FCz, Cz, C1, C2, CPz) in the emotional task condition. This procedure is essentially descriptive and can be considered post hoc because the TANOVA effect was significant. Moreover, it is compatible with the literature (Otten et al., 2006, 2010) and demonstrates that the different methods yield similar conclusions.

RESULTS

Behavioral Results

Study: Emotional and Semantic Judgments

The mean accuracy of semantic decisions was 83% (*SD* = 8), and mean RT for those decisions was 1092 msec (*SD* = 209 msec). The accuracy of emotional decisions was 67% (*SD* = 6.2), and mean RT for those decisions was 1123 msec (*SD* = 193). Emotional decisions were thus significantly less accurate ($t(20) = -9.88$, $p < .001$) than semantic decisions but not significantly slower ($t(20) = 1.13$, $p = .27$). Additional analyses were computed to evaluate whether the accuracy and time to respond to an item at study were related to later memory performance (by collapsing nonconfident hits and misses as in the EEG analyses below). In the semantic condition, accurate responses were significantly higher ($t(20) = 6.49$, $p < .001$) and RTs were faster ($t(20) = 3.26$, $p = .004$) for subsequently remembered words compared with forgotten words. In the emotion condition, accurate responses were significantly higher ($t(20) = 8.07$, $p < .001$), but RTs were not faster ($t(20) = -1.70$, $p = .10$) for subsequently remembered words compared with forgotten words.

Test: Recognition Memory

Recognition memory performance is shown in Table 1 and Figure 2. The mean RTs for correct answers were 976 msec (*SD* = 139 msec) in the semantic condition and 974 msec (*SD* = 156 msec) in the emotion condition and did not differ significantly. Accuracy of confident and not confident recognition was also assessed by the discrimination index *Pr* ($P_{\text{hit}} - P_{\text{false alarm}}$). For confident hits, the discrimination index *Pr* was 0.49 (70% correct answers) in the semantic condition and 0.47 (68% correct answers) in the emotion condition, which was significantly different from zero (semantic condition: $t(20) = 21.82$, emotion condition: $t(20) = 21.52$, both $p < .001$). The difference of the discrimination index between the two conditions approached significance ($t(20) = -1.94$ $p = .067$). For nonconfident hits, the discrimination index was not different from zero in both conditions (semantic condition: $t(20) = .23$, emotion condition: $t(20) = .10$, both $p > .8$). On the basis of these findings, only confident hits were considered as "remembered" items in the ERP analyses, because they were the only ones that reliably discriminated between old and new words. The reason for this procedure was to maximize the signal-to-noise ratio for SMEs by comparing the ERPs to items yielding confident hits versus those yielding non confident hits or misses (see also Discussion). The differences in mean RTs and proportion of responses between subsequently remem-

Table 1. Recognition Memory Performance

	Recognition Judgment			
Word Type	*Sure Old*	*Unsure Old*	*Sure New*	*Unsure New*
Proportion of Responses				
Old				
Semantic decision	0.70 (0.10)	0.05 (0.06)	0.20 (0.10)	0.04 (0.05)
Emotion decision	0.68 (0.11)	0.05 (0.07)	0.20 (0.11)	0.05 (0.07)
New	0.21 (0.11)	0.05 (0.05)	0.61 (0.16)	0.11 (0.15)
Mean Reaction Time (msec)				
Old				
Semantic decision	976.58 (139)	1650.17 (411)	1132.28 (189)	1533.45 (388)
Emotion decision	974.38 (156)	1540.25 (364)	1163.32 (177)	1518.68 (310)
New	1105.49 (232)	1729.61 (287)	1102.54 (160)	1568.47 (377)

Values are across-subject means (*SD*), $n = 21$.

bered and subsequently forgotten items (whereby the latter included unsure and missing answers) were significant in the semantic (RTs: $t(20) = -5.94, p < .001$; proportion of responses: $t(20) = 10.11, p < .001$) and emotion conditions (RTs: $t(20) = -6.49, p < .001$; proportion of responses: $t(20) = 8.05, p < .001$; Figure 2).

EEG Data

Subsequent Memory Effect in Pre- and Poststimulus Presentation (Replication of Previous Results with a Semantic Task)

In the analysis based on subsequent epochs of 100-msec duration, we identified a period from 1300 to 700 msec before stimulus onset that yielded robust evidence for SMEs.

In the replication part of our analysis, we initially considered the ERP waveforms in the conditions where cues indicated that a semantic decision task had to be performed. Afterward, we computed the same types of analyses for the emotion condition in the same time interval of −1300 to −700 msec.

In the semantic condition, the items that were subsequently remembered (vs. forgotten) showed a very similar pattern to that found by Otten et al. (2006, 2010) both before and after the words' onset (Figure 3). The potentials at frontal electrodes preceding the words that were later remembered were more negative-going than those preceding words that were later forgotten (maximum

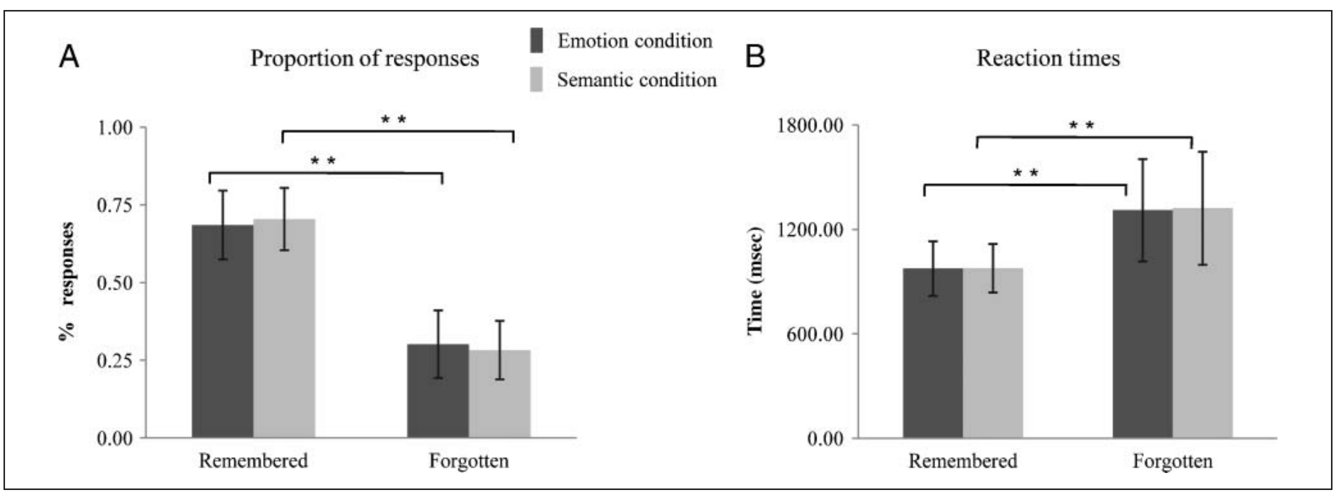


Figure 2. Behavioral measures at test. *t* Test differences: $^{**}p < .001$. (A) Proportion of responses averaged across subjects. Only confident hits were considered remembered items, whereas forgotten values include nonconfident hits and wrong answers. (B) RTs averaged across subjects. Only confident hits were considered remembered items, whereas forgotten values include nonconfident hits and wrong answers.

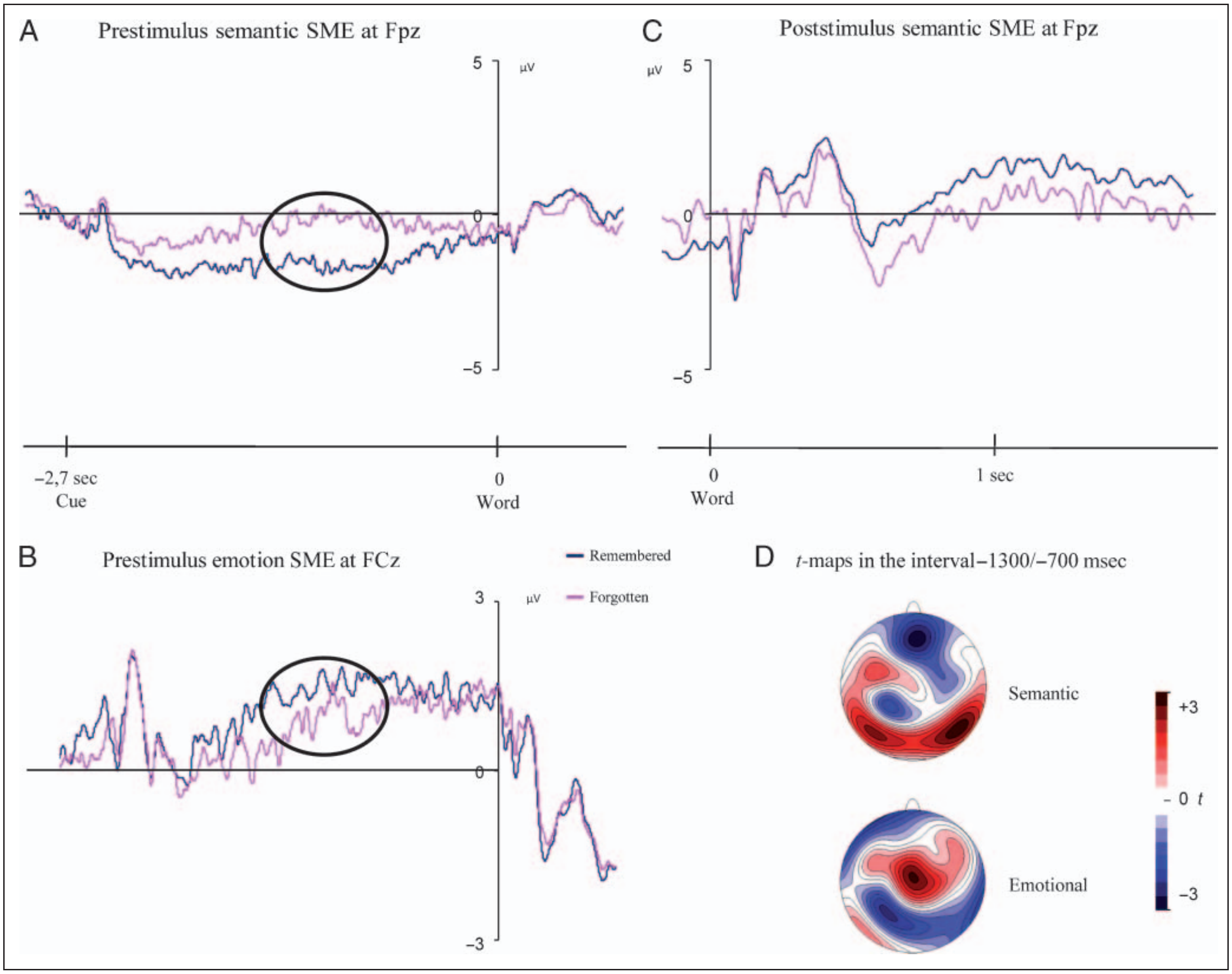


Figure 3. Pre- and poststimulus neural activities. Positive values are plotted upward. (A) Prestimulus activity predictive of encoding success in the semantic condition. Group-averaged ERP waveforms elicited by prestimulus cues at representative frontal electrode site Fpz. ERPs elicited by cues signaling an imminent semantic decision task (animate or inanimate) about an upcoming visually presented word are shown, overlaid according to whether the word was remembered or forgotten in the subsequent recognition memory test. The ERPs differed reliably before word onset according to later memory performance. The circle represents the period used for waveform quantification. (B) Prestimulus activity predictive of encoding success in the emotion condition. Group-averaged ERP waveforms elicited by prestimulus cues at representative fronto-central electrode site FCz. ERPs elicited by cues signaling an imminent emotional decision task (neutral or emotional) about an upcoming visually presented word are shown, overlaid according to whether the word was remembered or forgotten in the subsequent recognition memory test. The ERPs differed reliably before word onset according to later memory performance. The circle represents the period used for waveforms quantification. (C) Poststimulus activity predictive of encoding success. Group-averaged ERP waveforms elicited by a stimulus word at representative frontal electrode site Fpz. ERPs elicited by a visually presented word requiring a semantically based decision (animate or inanimate) are shown, overlaid according to whether the word was remembered or forgotten in the subsequent recognition memory test. (D) *t*-Maps showing the distribution of the SME (difference between remembered and forgotten words) in semantic (top map) and in the emotion (bottom map) conditions across the scalp in the time interval from 1300 to 700 msec before word onset.

difference at Fpz) and tended to have an inverse polarity at posterior sites (see Figure 3, showing a *t*-map of the average potentials from −1300 to −700 msec). Furthermore, for the reasons we mentioned earlier, we averaged the potentials at the frontal electrodes (Fp1, Fp2, Fpz, AF1, AF2) and compared remembered and forgotten words with an ANOVA for repeated measures. This comparison yielded a significant main effect in the expected direction (remembered more negative than forgotten) in the prestimulus interval from −1300 to −700 msec ($F(1, 20) = 14.933$, $p = .001$). We therefore successfully replicated the previously reported scalp location and direction of the prestimulus SME.

For the poststimulus effects elicited by study words (i.e., after the stimulus presentation), we confirmed Otten et al.'s finding of more positive ERP potentials over frontal electrodes related to the subsequently remembered words, as has been extensively reported in the literature (Otten, Sveen, & Quayle, 2007; Otten et al., 2006; Paller & Wagner, 2002; Sanquist et al., 1980). The *t*-maps of the averages of the post-stimulus SME relative to three equal intervals of 400 msec each after the stimulus onset

(0–400 msec, 400–800 msec, 800–1200 msec) showed a generalized fronto-central positivity and a posterior negativity consistent with previous studies (Otten et al., 2006, 2007).

To detect possible attention-related effects on the amplitude of P1 and N1 components elicited by the cues and by study words, we measured mean amplitudes of the group averaged waveforms within an interval of 40 msec around the peaks of these deflections. P1 and N1 amplitudes elicited by the cues were measured respectively between 80 and 120 msec and 180 and 220 msec at the electrode sites O1 and O2, where the attentional-related effects are usually maximal. The analyses contrasted postcue amplitudes of subsequently remembered and forgotten words, and no significant effects were found: P1 in the emotion ($t(20) = 1.32, p = .201$) in the semantic ($t(20) = 0.45, p = .654$) conditions; N1 in the emotion ($t(20) = 0.67, p = .508$) and semantic ($t(20) = 0.49, p = .627$) conditions.

At the same electrode sites, P1 and N1 amplitudes elicited by the study words were measured between 80 and 120 msec and 140 and 180 msec, respectively, contrasting amplitudes of subsequently remembered and forgotten words. Only the difference in P1 in the emotion condition was significant ($t(20) = 2.54, p = .019$), but no effects were found in the semantic condition ($t(20) = 0.52, p = .609$) nor were any found in N1 in the emotion ($t(20) = 0.87, p = .394$) and semantic ($t(20) = 0.03, p = .974$) conditions.

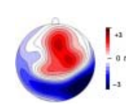
There remains however some uncertainty about the latency of the effect, which seems to be a general problem when investigating the prestimulus SME: Otten and colleagues first reported an effect that was largest between −250 and 0 msec before the words' onset (Otten et al., 2006). In a follow-up study, the authors showed the appearance of the effects in another time window, namely from 750 to 1250 msec after the cue onset (Otten et al., 2010). Finally, in a new article, the same group presented the analyses in three different intervals, 200–300, 300–600, and 600–1100, after the cue onset to allow for comparison with reward-related activity (Gruber & Otten, 2010). In the present study, the negative-going ERP modulation was maximal in the interval between −1300 and −700 msec before the stimulus onset, partially overlapping the analysis windows used in the last two articles cited above. The variation in the exact time window exhibiting the maximal prestimulus effects across studies might reflect differences between experimental paradigms and experimental settings.

Subsequent Memory, Emotional, and Semantic Interaction Effect

In the second part, we considered both emotional and semantic task effects and their interaction with performance using randomization methods in the prestimulus time interval from −1300 to −700 msec (Table 2). In this time window, paired TANOVAs for each condition yielded a significant effect in the semantic condition ($p = .028$), a significant effect in the emotion condition ($p = .048$), and a significant interaction ($p = .012$). Moreover, the topographic difference between emotional and semantic remembered words was highly significant ($p < .001$), whereas the difference between emotional and semantic forgotten words was not significant ($p = .314$; see also Figure 5).

The spatial distribution of these effects was further displayed and explored on the scalp level with t-maps as shown in Table 2. In the interval of interest, the t-map contrasting remembered with forgotten words in the semantic condition showed a frontal negativity with the minimal t value at the electrode Fpz ($t = -3.652$) and a bilateral posterior positivity with the maximal t value at the left electrode O1 ($t = 2.498$). This pattern is completely consistent with the prestimulus SME already reported in the literature (Otten et al., 2006, 2010). In the same time window, the t-map contrasting remembered with forgotten words in the emotion condition showed a different distribution with a pronounced central positivity with the maximal t value in the electrode FCz ($t = 2.872$) and minimal value

Table 2. TANOVAS and GFP Significance

Time Interval before 0 (1300–700 msec)	*Emotion Condition (R–F)*	*Semantic Condition (R–F)*	*Emotion (R–F)–Semantic (R-F) Interaction*
Quantitative			
Amount of activation GFP	$t = -4.589$	$t = -3.566$	$t = 1.325$
	$p = .0002$	$p = .002$	$p = .200$
Qualitative			
Topography TANOVAS	$p = .048$	$p = .028$	$p = .012$
t-maps			

(R–F) indicates the difference between Remembered and Forgotten words.

on the left posterior electrode P5 ($t = -4.008$). Finally, the t-map related to the interaction (contrasting the SME related to the emotion with the SME related to the semantic condition) showed a diffuse fronto-central positivity with the maximal t value on the electrode AF2 ($t = 2.501$) and a posterior negativity with the minimum t value in the left electrode PO10 ($t = -3.216$). Consistent with the TANOVA results, the t-map of the difference between emotional and semantic remembered words was associated with a pronounced central positivity with the maximal t value in the electrode CP3 ($t = 4.340$) and with a diffuse posterior bilateral negativity with the minimal value at the electrode PO10 ($t = -4.661$). These findings indicate that the main differences between the two conditions mainly rely on the activity associated with the remembered words.

Differences in amplitude independent of topography were analyzed on the basis of the differences in GFP (Table 2, Figure 4). In the interval of interest, we observed that forgotten words were associated with a higher GFP than remembered words both in the semantic condition ($t(20) = -3.566$, $p = .002$) and in the emotion condition ($t(20) = -4.589$, $p = .0002$), but this was apparently independent of the task condition, because the double difference was not significant ($t(20) = 1.325$, $p = .2$). In the same interval, when the semantic and emotion conditions were collapsed, the difference between the remembered and the forgotten items was also significant ($t(20) = -4.234$ $p < .0001$). The significant t values were in all cases negative, indicating higher prestimulus activity for the subsequently forgotten versus the subsequently remembered items.

Finally, and following the replication analysis of the SME in the semantic task condition, we computed an ANOVA comparing remembered and forgotten words with an ANOVA for repeated measures across five central electrode sites (FCz, Cz, C1, C2, CPz). This comparison yielded a significant main effect in the expected direction (remembered more positive than forgotten) in the prestimulus interval from −1300 to −700 msec ($F(1, 20) = 8.587$, $p = .008$).

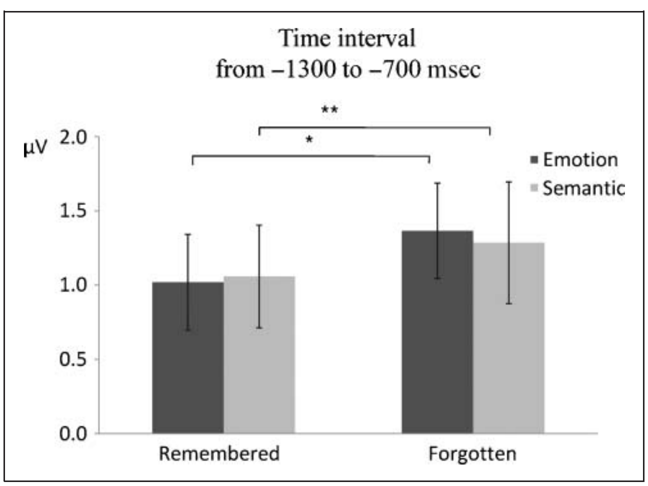


Figure 4. t test differences in GFP: $^{**}p < .0002$, $^{*}p < .002$. Note that the standard deviations of the mean values shown do not correspond to the standard deviation employed for the paired t tests in the time interval from 1300 to 700 msec before the word onset.

DISCUSSION

The goals of the present study were to identify different patterns of electrical brain activity preceding the stimulus presentation related to remembered and forgotten words in two distinct encoding conditions (emotion/semantic) in an incidental learning setting. For the semantic condition, this was a planned replication of previous findings (Otten et al., 2006), whereas the emotion condition and the comparison of the emotion with the semantic conditions represent the novel parts of the study.

The data showed two main results that were consistent with our predictions and aims. First, the results revealed distinct electrophysiological activity before stimulus onset for subsequently remembered versus forgotten items in both encoding conditions. Using the same procedure employed by Otten and colleagues gave us the opportunity to replicate their findings and extend our insight into the prestimulus SME and into the relation between emotional processing and memory formation. The successful replication of the semantic condition confirms the quality and reliability of our results.

Second, the ERPs related to the prestimulus SMEs elicited in the emotion and semantic conditions were clearly distinguishable, as they were associated with differences in topography. This suggests that the two conditions recruited at least partially different brain areas that were also involved in memory formation. Alternatively, this topographic difference might also indicate that a common set of brain areas was activated in association with the incidental encoding, but that the task type consistently altered the relative contribution of the involved brain areas to the measured scalp electric fields.

These findings point to several important implications for current and future research: (1) the role of prestimulus activity in memory formation was assessed in relation to emotional processing; (2) in the two different encoding tasks the formation of a lasting memory reflects a qualitative difference between emotional and semantic information processing; (3) the preparation for an emotional semantic evaluation and for a nonemotional semantic evaluation affects the location and/or the relative electrophysiological activity of brain regions involved in these tasks. This change in distribution of brain electric activity has a consistent modulatory effect on memory formation. Our data therefore provide evidence that episodic encoding is supported by multiple brain regions which differ in their location and/or in their relative electrophysiological activity and are involved

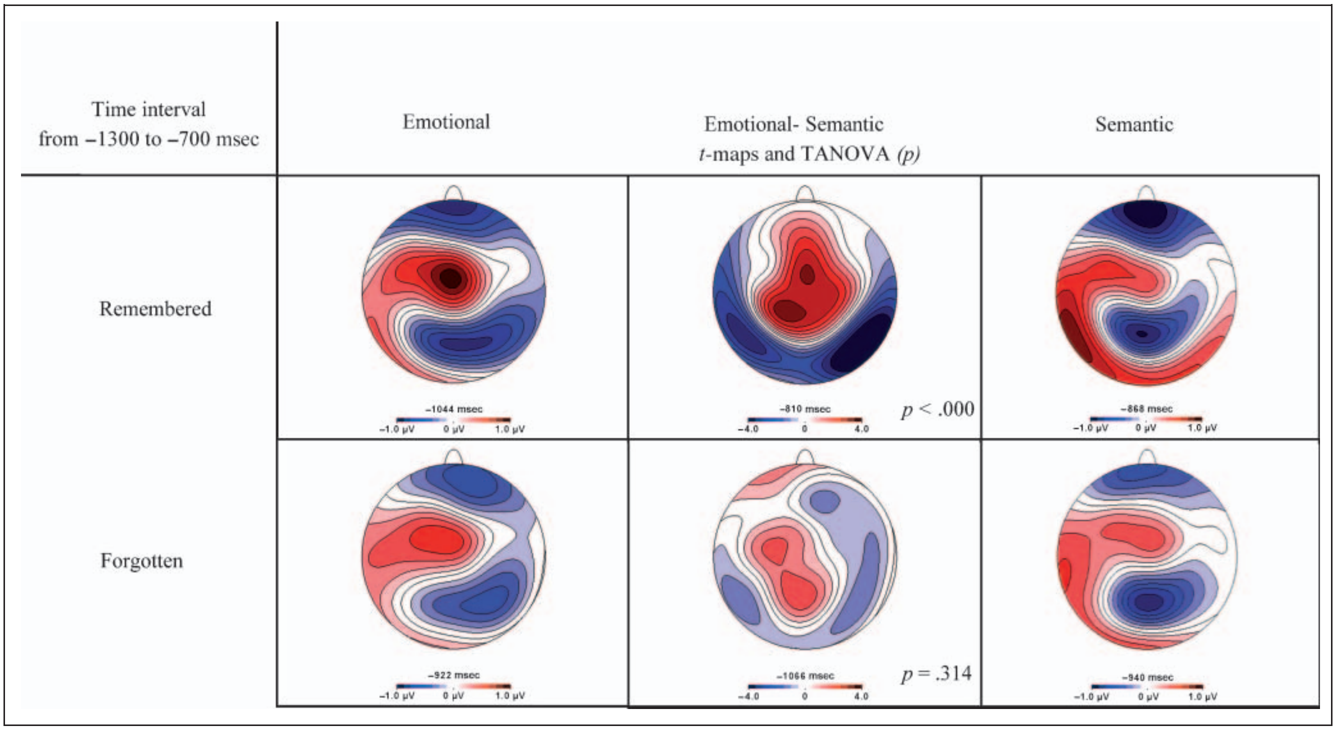


Figure 5. ERP scalp distributions in the time interval from 1300 to 700 msec before word onset. Spline maps (first and third columns) showing the distribution of subsequently remembered and forgotten words in each condition. *t*-Maps (second column) showing the distribution of the ERP differences across the scalp between semantic and emotional remembered words (top row) and between semantic and emotional forgotten words (bottom row).

in the analysis of the different components of a word's meaning.

Qualitative and Quantitative Differences between Emotional and Semantic SMEs

The key finding of the present study, namely an SME specific to the emotional task, was found as a topographic difference in ERPs in a time window of 1300–700 msec before the stimulus onset. In the same time window, we also found evidence for a topographic SME in the semantic task condition. The conclusion that the SME of the two task conditions was different was also supported by a significant interaction in a 2 × 2 TANOVA. The interaction results confirm that the semantic nature of the study tasks—emotional or nonemotional judgment—differentially modulates ERPs. This provides evidence that there are two distinct prestimulus SMEs related to different types of meaning-based tasks. Both of them are detectable before target presentation, and they can be distinguished by their consistently different topographies. This indicates that there is more than one way to prepare for encoding an upcoming event that will be semantically processed. One of these ways requires emotional elaboration processes, and the other not, but both are involved in the processing of the different components of a word's meaning.

Moreover, these topographic differences reflect qualitative neural differences in the ERPs, indicating either a distinction in the topographic distribution of active sources and/or neurophysiologically distinct activity in a common set of brain regions related to subsequently remembered and forgotten items. The additional finding about the topographic difference between the neural activity associated with the emotional and nonemotional judgments for the remembered words and the absence of this effect for the forgotten words indicates that the crucial distinction between emotional and nonemotional processing is mostly related to successful encoding (Figure 5).

In general, the qualitative differences correspond to different distributions of the activity level recorded at each single electrode over time and are depicted with topographic maps. This distribution allows estimating the localization of differentially active sources on the scalp. On the other hand, when we talk about quantitative differences we refer to a measurement of the amount of activity by considering the data from all recording electrodes simultaneously through the GFP (Lehmann & Skrandies, 1980). Assessing the quantitative differences using GFP in this experiment, we found that it was consistently higher for forgotten than for remembered words, both in the emotion and in the semantic task conditions, but no differences between the task conditions were detectable. This finding indicates that, in the prestimulus interval, the subsequently forgotten items were constantly associated with a higher level of activity compared with remembered ones. This result has never been reported before and therefore needs an independent replication.

The following interpretation is thus speculative: If we assume that higher prestimulus activity is associated with a more task-focused state, we may speculate that having less task-focused activity permitted to invest more cognitive resources in the execution of other "irrelevant" tasks. These may have included incidental encoding of words. Similar observations have also been made when the relation between affect and attentional filters were investigated (Rowe, Hirsh, & Anderson, 2007).

Because there was no significant interaction in the GFP between the two conditions, hence no overall quantitative but only topographic qualitative differences in the SMEs, the brain regions accounting for the GFP difference in the emotional task were different or provided a different contribution to those accounting for the GFP difference in the semantic condition. This indicates that a common underlying mechanism cannot be assumed. Therefore, the present findings suggest the existence of multiple task-specific functional neural systems which support memory formation. Although similar conclusions were mentioned in another study in which a qualitative difference in SMEs across deep and shallow study tasks was shown (Otten & Rugg, 2001), here we can further specify that the cognitive processes related to memory formation can already be distinguished before stimulus onset, depending on the different semantic nature of the study task.

Regarding the behavioral data we found neither an RT nor an accuracy advantage for emotional versus semantic conditions in the recognition memory task. Instead, we found a clear advantage (shorter RTs) in both conditions for subsequently remembered versus forgotten items, obviously representing the less efficient retrieval of words that were not sufficiently well encoded. One might have expected better recognition performance for the emotional judgment task than for the nonemotional decision task. One possible explanation for why this was not the case is that in our experiment, in the emotion condition, the subject had to distinguish between neutral and emotional words, and this means that they were not instructed to experience the feeling induced by the words as is commonly reported in the literature (e.g., Dolcos, LaBar, & Cabeza, 2004; Dolcos & Cabeza, 2002; Canli, Zhao, Brewer, Gabrieli, & Cahill, 2000). Moreover it is also acknowledged in the literature that words tend to elicit a weaker emotional effect compared with pictorial stimuli (Liu et al., 2009; Kensinger & Schacter, 2006; Dolcos & Cabeza, 2002), and thus, choosing word stimuli was a conservative decision. From our data, we can conclude that this type of emotional decision task is not sufficient to determine better memory performance and that one of the factors necessary to observe this advantage might be feeling the subjective experience of the emotion itself.

A crucial aspect of the experimental design to be discussed in relation to the prestimulus activity is the random presentation of cue types. The randomization insured the unpredictability of the intermixed trials sequence and might be the cause of the flexibility and transient nature of the encoding-related prestimulus effects. These two characteristics allowed renewal of the effect on a trial-by-trial basis over a relatively short timescale (5.2 sec), regardless of the type of semantic task induced from the cue and regardless of the input modality (Otten et al., 2006, 2010). Another important feature characterizing our experimental design was the use of dual-meaning words for joint examination of emotional and semantic cueing effects on the two related preparatory processes. The same dual-meaning words were used as target stimuli in both conditions, the only difference being determined by the cues (X or O). Thus, any difference between emotional and nonemotional semantic preparatory processes or effects could be directly assessed without being confounded by influences exerted by the word material.

Different Hypotheses for the Prestimulus SME

The functional significance of the prestimulus effects and of the mechanisms through which prestimulus activity modulates memory encoding is still not fully understood. The prestimulus effects could possibly be determined by state-dependent random fluctuations of neural activity in which such processing takes place. However, if this were the case, we would hardly have found the systematic differences reported above between the emotional and nonemotional decision task. Furthermore, it would be difficult to explain why these effects become evident only in connection with semantic processing—a deeper level of processing—and not with orthographic and phonologic processing, which are shallower levels (Otten et al., 2006, 2007, 2010). Nevertheless, it is not possible to exclude an indirect influence of random neural states on the prestimulus SMEs. Alternatively, these prestimulus SMEs could reflect the efficiency through which the cues activate general attentional mechanisms for the allocation of resources in anticipation of the stimulus presentation. Accordingly, we find in the study phase a higher proportion of responses for subsequently remembered versus subsequently forgotten items in both emotional and nonemotional semantic conditions and faster response times in the semantic condition. However, attention sensitive ERP deflections P1 and N1 elicited by cue and words did not differ, with the exception of a post-word P1 effect in the emotion condition. Thus, and in line with previous studies (Gruber & Otten, 2010; Otten et al., 2006, 2010), our data provide neither strong support for this interpretation of the effects nor sufficient evidence to rule out the interplay between the prestimulus SME and a differential attentional recruitment. Another possible interpretation of these prestimulus effects could be proposed in terms of "task set" intended as "a task-dependent cognitive state, mode, or set that is maintained for the duration of the task" (Dosenbach et al., 2006). In the present experiment, the "task set" switching induced by the cue-related information can thus also be considered an operational measure of executive control

(Rushworth, Passingham, & Nobre, 2002). This switch can be related to the generation and maintenance of two different "task sets," in one case linked with emotional processing (emotional or neutral judgments) and in the other with nonemotional semantic processing (animate or inanimate judgments). In summary, on the basis of our results, we can neither exclude nor accept any of these hypotheses in toto, and only future experiments will clarify the exact contributions of these mechanisms to the prestimulus effects.

In conclusion, we have demonstrated the existence of a semantically elaborated emotional prestimulus SME that differs in topography from a semantic prestimulus SME. Hence, the neural sources associated with successful and unsuccessful encoding differ between these two conditions. Another possibility would be that these topographic differences induced from the two different semantic tasks are determined by neurophysiologically distinct activity in the same set of brain structures. Therefore, our findings suggest that memory formation can be tuned by multiple brain structures which differ in their location and/or in their relative contribution to the measured scalp electric fields and are related to the processing of different semantic components of a word's meaning. These components can also be determined by emotional elaboration processes, which possibly interplay with preparatory encoding processes. The finding of two distinct prestimulus SMEs related to different topographies further supports this conclusion and suggests the existence of multiple task-specific neural systems which support memory formation. Additionally, this conclusion is also consistent with results of a recently published study (Gruber & Otten, 2010) where the authors demonstrate the existence of different kinds of prestimulus activity that influence encoding, reflecting another type of semantic preparation. A possible interpretation of these results in functional terms is that these topographic differences reflect the existence of different semantic networks which mediate the processing of a word's meaning. Whether these networks belong to a common higher semantic network or function as independent units is difficult to assess with the present data. However, our results are compatible with the idea of a dynamic semantic network (Kissler et al., 2006; Barsalou, 1999; Pulvermuller, 1999) composed of multiple networks reflecting processes behind the various aspects of a word meaning, which might include the affective nature of stimuli. Hence, a full understanding of the neural determinants of successful memory encoding should also consider the functional role of the differential prestimulus activities through the investigation of different types of preparatory semantic processing.

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